Compact Tunable Optical Sensors

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This project reduces to practice a scanning Fabry-Perot (FP) cavity-based absolute conditioner, an "optical force probe" (OFP), and an "optical gap gauge" (OGG). Two tasks were attempted to establish the FP conditioner: 1) fabrication of a transimpedance amplifier to reduce detection circuitry noise for observing fringes; and 2) experimental verification of a synthesized broadband light source using two or three different wavelength LEDs. We also demonstrate experimental results for the fiber-based OFP that is capable of sensing compressive loading transverse to the long-axis of an optical fiber. We have achieved experimental results for a fiber-based OGG capable of measuring displacements transverse to the long axis of a fiber. These devices constitute a class of compact optical sensors realized through the integration of microfabricated and machined components and strain sensitive fiber Bragg grating (FBG) elements.

Project Goals

For the conditioner, a new amplifier is needed primarily when using an incandescent bulb or broadband light source for illumination, since the optical intensity in the fiber is very low with these sources. Furthermore, this amplifier will help make more accurate measurements when using the brighter LED light sources.

The goals of the OFP and OGG are to demonstrate tunable sensors appropriate for weapons and other load and displacement measurements. The sensors must be inherently safe and able to accurately perform measurements over long periods of time without access to the sensor.

Relevance to LLNL Mission

LLNL's stockpile stewardship mission demands microsensors and signal conditioning that are able to survive harsh environments of temperature, vibration, and radiation while maintaining very small form factors, inherent safety, and long-term accuracy. These constraints pose significant challenges and require low-power methods, microscale features and carefully configured devices and material choices. These technologies address these performance goals.

FY2007 Accomplishments and Results

For the optical conditioner, a new amplifier was built that gave a 10-dB improvement in signal/noise ratio.

A multi-LED package was obtained to experiment with the synthesized light source. It consisted of LEDs ranging in wavelengths from 570 nm to 850 nm, covering most of the bandwidth of interest. Two problems with this new light source were a significant difference in intensity between the shortest wavelength LED and the longest wavelength LEDs, and a spacing of the LEDs that would not allow simple coupling of multiple LEDs into one fiber. Several experimental setups were tried to solve these problems.

Uniform intensity can be achieved at the cost of some loss of intensity by simply attenuating the light from the brighter LEDs; however, coupling multiple LEDs into a fiber proved to be a more difficult problem. It will require the implementation of a special coupling structure, which will be addressed in a future effort.

Figure 1 shows a 3-D schematic of the OFP. The device is a hybrid optical

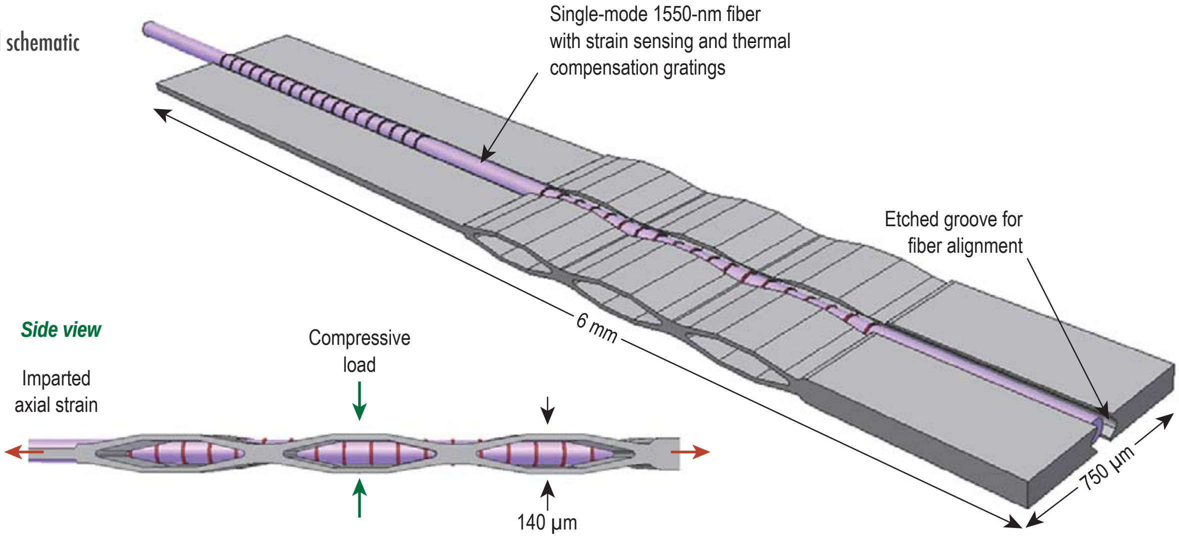

Figure 1. Three-dimensional schematic of the OFP.

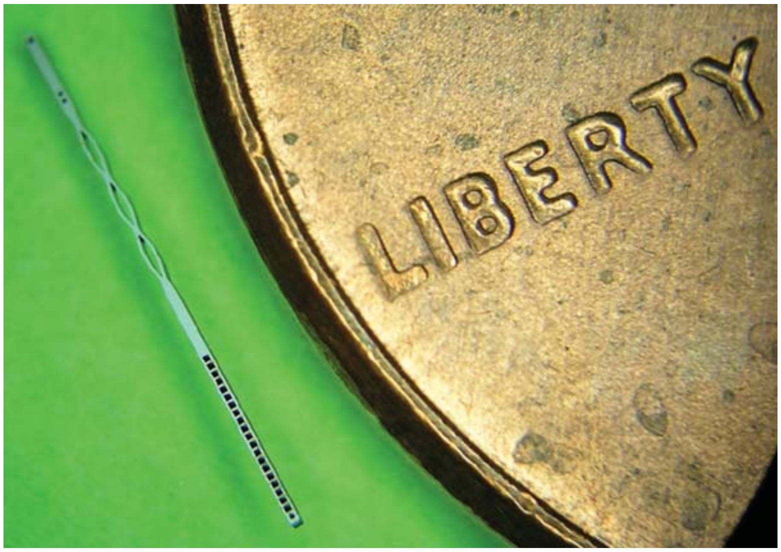

Figure 2. A microfabricated silicon component of the OFP, pictured next to a US penny for scale.

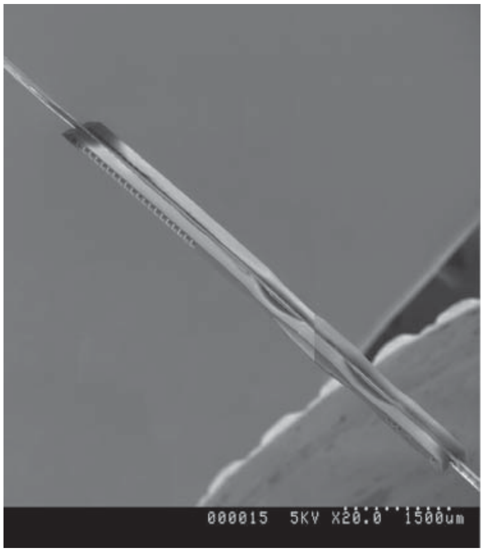

Figure 4. SEM of a completed OFP. This view was generated by stitching together two separate images.

fiber sensor consisting of a fiber-based strain-sensing element integrated with micromachined transducers. The strain-sensing element consists of a single-mode 1550-nm optical fiber containing two FBGs (one for load sensing, one for thermal compensation). The transducer elements, an example of which can be seen in Fig. 2, consist of single-crystal silicon (SCS) structures that are micromachined to define geometry for fiber alignment as well as mechanical transduction, converting an applied compressive load to a tensile strain in the fiber. Finite element simulations are used to properly dimension the flexure elements.

A typical axial strain response is included in Fig. 3. Under an applied compressive load, the transducers generate a tensile strain along the fiber, increasing the periodicity of the FBG and resulting in a red shift in the peak reflectance that can be recorded via standard FBG interrogation hardware.

An SEM of a completed OFP is presented in Fig. 4. Data from a single-transducer sensor is presented in Fig. 5. In this experiment, the sensor was subjected to a compressive load resulting in an applied pressure varying from 40 to 180 psi. The sensor exhibits a repeatable linear response in the range of 60 to 180 psi with a sensitivity of 6.52 pm/psi. Assuming a strain-induced peak shift of 1.21 pm/$\mu\varepsilon$ at 1550 nm, this converts to an axial strain transduction of 5.38 $\mu\varepsilon$/psi for this geometry.

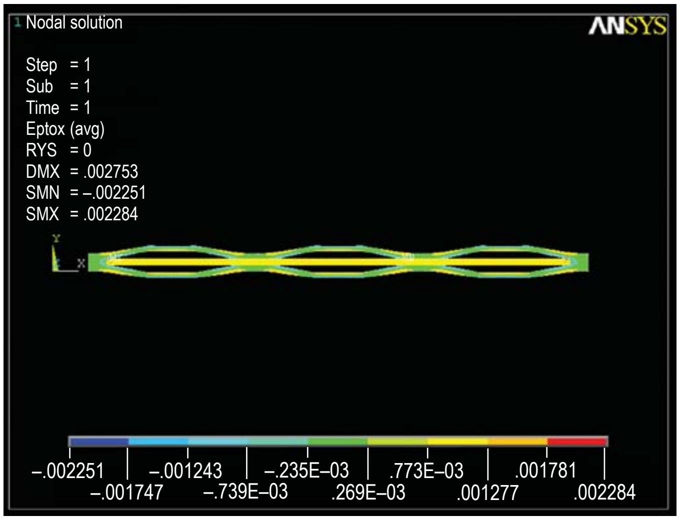

Figure 3. Finite element simulation of the OFP strain response. The device modeled here has three sets of 40-µm flexures. At 200 psi, 773 µε is imparted to the optical fiber sensor.

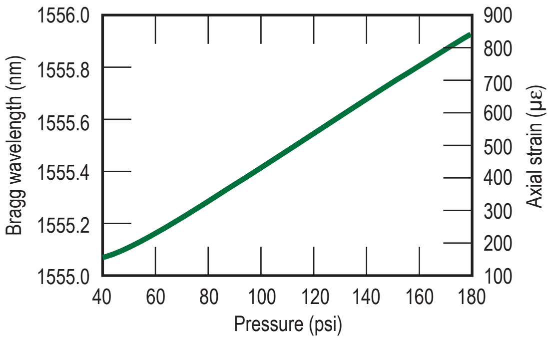

Figure 5. Typical response of the single-transducer OFP to a loading cycle up to 180 psi.